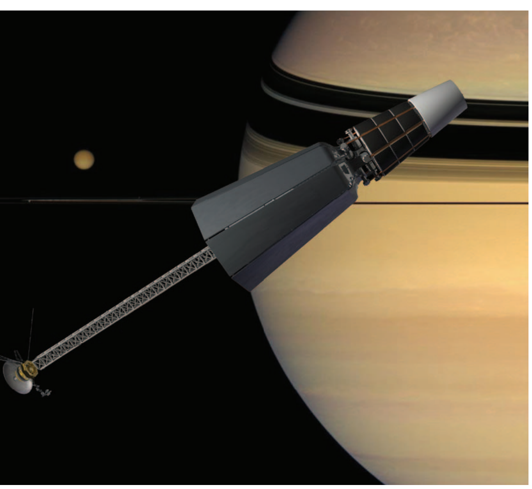
spotlights

Interplanetary Mission Fission

"When you design a spacecraft to explore the solar system, you're always limited by weight and power," says Patrick McClure, a mechanical engineer at the Los Alamos National Laboratory. Too much weight makes it too expensive to get off the ground, and too little power restricts what it can do. For example, the Curiosity rover on Mars, which employs a radioisotope thermoelectric generator (RTG) fueled by a plutonium power source manufactured at Los Alamos, must carefully manage a meager 100 watts of power in order to move around and perform science. But with a lightweight, high-output power source, solar system scientists could obtain data from a much larger suite of power-consuming instruments.

"Scientists always want more power," McClure says, "and we want them to have it."

McClure, working with Los Alamos colleague David Poston and David Dixon (formerly of Los Alamos), plus others at the NASA Glenn Research Center and National Security Technologies, LLC, built a successful, small-scale demonstration unit of a fission-based spacecraft power source.



Concept for a spacecraft (at the left end of the boom) powered by a new type of fission reactor (at the right end) as demonstrated by the DUFF experiment. The long boom keeps the spacecraft at a safe distance from the reactor to protect it from damaging radiation.

CREDIT (BACKGROUND): CASSINI IMAGING TEAM, SSI, JPL, ESA, NASA

Known as DUFF (Demonstration Using Flattop Fissions—an extension of an earlier tabletop experiment that resembled the flat top of an aircraft carrier), the system uses highly enriched uranium to drive a sustained nuclear reaction that automatically adjusts to supply whatever amount of power is needed, up to a maximum amount. Most spacecraft are limited to 150 or 200 watts, but a DUFF-type fission power system is expected to provide 1000 watts for the life of the mission, enabling the spacecraft to do significantly more science.

The new power source will not be NASA's first fission reactor in space. Back in 1965, a space vehicle called SNAP-10A attempted to fly a much larger fission reactor requiring an active control system. That control system malfunctioned, permanently shutting down the reactor in just 45 days.

"What makes this new system different is its simplicity," Poston explains. "DUFF uses a heat pipe with no moving parts and a simple Stirling engine that's already flight qualified." The heat pipe itself is a Los Alamos invention that carries heat away from the reactor and into the Stirling engine without the circulating fluids and pumps used in conventional heat exchangers. The heat energy delivered by the heat pipe is converted by a reliable, high-efficiency Stirling engine into mechanical energy, which is then converted to electricity by a small alternator. The combined system is lightweight, adaptable, and maintenance-free for more than a decade, making it ideal for missions to the outer solar system, where solar power is not an option.

The only alternative power source available for such deep-space missions is the plutonium-based RTG. It is long-lived and has no moving parts, but because plutonium production is limited, it can take several years to obtain enough to make a single RTG. McClure and others argue that DUFF-like fission power could become plentiful, freeing RTGs to be used in the missions for which they are particularly well suited. And NASA seems to agree, stating that such "small fission" designs will be an important addition to their capabilities portfolio in the future.

"In addition to benefitting current planetary science," Poston says, "this system may serve as a stepping stone to enabling technologies for future space exploration. Higher-power fission systems will ultimately be needed for human outposts on the Moon and Mars, as well as for propulsion systems to transport spacecraft and crews across the solar system and beyond." LDRD

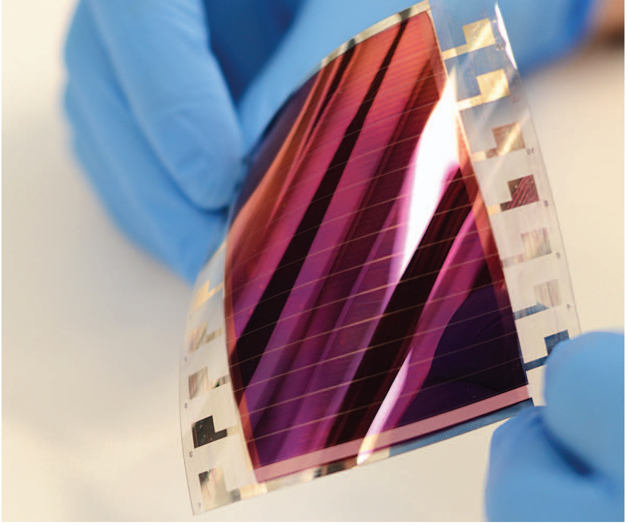
—Craig Tyler

Powered by Plastic

Do you want an environmentally friendly way to recharge your phone and other devices? With organic photovoltaic (OPV) solar cells, you could just slap a thin plastic film onto the nearest window to collect power from the Sun. The only obstacle is efficiency, which determines how much power an OPV can obtain from sunlight. At present, they are only about 8 percent efficient—three to four times less efficient than standard, solid-state solar panels.

To improve efficiency, researchers need to understand the devices' complex submicroscopic structure. OPVs are made from a sandwich of organic layers, each less than 100 nanometers thick (around a thousand times thinner than a human hair). Because the layers are so thin, much of their physics is dominated by the detailed features of the interfaces between them. But imaging these interfaces is difficult because x-rays, normally used to "see" inside objects, are ineffective with the light elements in the organic materials and tend to damage them. Neutrons, however, penetrate to the interfaces being studied, reflect well at the interfaces, and do not damage OPV materials.

Adam Moulé of the University of California at Davis and Jarek Majewski of the Los Alamos Neutron Science Center became the first to reveal the internal structure of OPV-



Organic photovoltaic solar cell

CREDIT: I-MEET INSTITUTE, MATERIALS FOR ELECTRONICS AND ENERGYTECHNOLOGY, FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NÜRNBERG, GERMANY.

layer interfaces with neutron reflectometry. The team discovered a complex relationship between the internal structure—including the morphology of the interfaces and the choice of metal used for the electrodes—and the overall device efficiency, suggesting promising avenues for research to improve efficiency.

Success could make OPVs extremely practical because they are cheaper to manufacture than standard solar cells, and they can be applied easily to rigid or flexible surfaces, such as walls and even fabrics. Majewski particularly likes the idea of a tent covered with OPVs, redefining the meaning of "roughing it" in the wilderness. LDRD

—Craig Tyler

Graphic Math

He did it for love.

Nathan Lemons, a young mathematician with the Laboratory's Applied Mathematics and Plasma Physics group, and several colleagues have done something that few people can lay claim to—they have proven a theorem in graph theory. Invented by Leonhard Euler in 1735 to solve the Königsberg Bridge problem (see right), graph theory has evolved into its own subfield of mathematics, with applications in many areas of science, including chemistry, linguistics, sociology, and, in particular, computer science. Lemons' theorem, which has so far been viewed with interest by fellow graphematicians, is already being applied to certain aspects of cyber security, with a slew of other applications waiting to be explored.

Graph theory deals with relationships between pairs. The namesake graphs are made up of nodes and edges, with each edge connecting a pair of nodes together. One defines rules, say, that each node must be connected to an even number of other nodes. Then one considers how to enumerate and classify all graphs that satisfy the rules and to flesh out the how and why of those graphs' properties and behaviors. The math is abstract and can quickly become challenging, but there is a richness and beauty to it that Lemons finds compelling. Others, however, are motivated to study graphs because they are far and away our best hope for understanding the properties of real-world networks.

Networks are the backbones of modern civilization, and they're all different. Cellular networks, the power grid, the interstate highway system, financial networks, Facebook, the World Wide Web—each emerged for different reasons, grew by different sets of rules, and consequently, each has different properties. Surprisingly little, however, is understood about the properties of networks in general, and a question as basic as "Does this particular network become more robust as it grows larger?" is often difficult to answer.

Enter graph theory. It can be viewed as the fundamental mathematics for the study of networks, with graphs seen as structures designed for the express purpose of being analyzed. That's not to say that all network questions will soon be answered. There's the map versus the territory dilemma, that is, whether the insight gained by studying graphs translates into an understanding of real-world networks. There's no simple answer.

So, for example, Lemons' theorem pertains to what are known as random intersection graphs. Defining the graphs by a parameter k, in the limit where the number of nodes goes to infinity, Lemons proved that the graphs undergo a phase transition and abruptly change from being disconnected to being highly connected as k goes from a value of less than one to a value greater than one.

Will the theorem help a teen get more friends on Facebook? "Probably not," says Lemons honestly. It might, however, provide some insight into how to distribute cryptographic keys in a wireless sensor network. Suppose two sensors can talk to each other securely if they share a cryptographic key, but every sensor cannot share the same key, nor can every sensor have a complete set of keys. The theorem gives conditions for achieving a fully connected network in the case where every sensor receives a small number of keys that are chosen at random from the complete set of keys.

For his part, Lemons is unconcerned whether the theorem contributes to anything other than the greater body of knowledge. As he says, "I just love the work, and I'm happy I could contribute."

— Jay Schecker

The Kaliningrad bridge problem: Starting at any point, can you walk across all seven bridges, crossing each bridge only once? Kaliningrad, Russia, is the former city of Königsberg, Prussia. In 1735, Leonhard Euler proved the equivalent Königsberg bridge problem to be impossible. Inset: The problem represented as a graph.